New Filter Bank for Graphics Equalizer Implementation

Background of the Invention

5   **Field of the Invention**

This invention relates to circuits and a method for implementing graphics equalizers utilizing a filter bank arrangement for use in audio and electrical systems. More particularly this invention relates to circuits and a method utilizing cascaded recursive digital filters whose arrangement has the advantage of not

10   distorting the spectral characteristics of magnitude and phase and does not delay the signal.

Description of Related Art

Today, conventional filter banks are implemented using parallel

15   arrangements. In Fig. 1, the input signal 150 is fed into a parallel bank of bandpass filters F1, F2, F3, ...Fm (110, 120, 130, 140). Each bandpass filter filters and selects one channel of the signal for gain adjustment by a gain control circuit G1, G2, G3, ... Gm (170, 180, 190, 195) in series with each parallel filter element. The frequency responses of the various channels of the filter bank are

20   shown in Fig. 2. In Fig. 2, F1, F2, F3, ...Fm (210, 220, 230, 240) are the center frequencies of the bandpass filters of Fig. 1. In Fig. 1, the outputs of all of the gain controls are summed 198 to produce the final output 160. A common problem with graphics equalizers built using the structure of Fig. 1 is that when all of the channel gain controls, Gm, are set to unity in order to create a flat

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response, the output of the filter bank is not an exact replica of the input. The output contains phase and amplitude distortion. Fig. 3 shows a typical frequency response plot 310 for the above conventional graphics equalizer when all of the channel gain settings, Gm are set to unity in a low cost filter bank

5   implementation. In addition, in the conventional parallel filter bank implementation of Fig. 1, the output is a delayed replica of the input when all of the channel gain control variables are set to unity.

10   U. S. Patent 4,284,965 (Higashi, et al.) "Tone Control Device" describes a tone control device comprised of multiple mixers and at least one band rejection filter. The device allows independent adjustment of the center frequency, Q value, and gain independently.

15   U. S. Patent 5,524,022 (Kihara, et al.) "Digital Graphic Equalizer" describes a digital graphic equalizer used to obtain a boost characteristic and an attenuation characteristic using band pass filters constituted by a digital filter and an adder.

      U. S. Patent 5,418,859 (Cho) "Correcting apparatus of sound signal distortion

20   by way of audio frequency band segmentation" describes a correcting apparatus of sound signal distortion by means of segmenting the audio frequency band more heavily in the low frequency bands than in the high frequency bands.

      U. S. Patent 4,891,841 (Bohn) "Reciprocal, Subtractive, and Audio Spectrum

25   Equalizer" describes an equalizer circuit having adjustable band pass filters

connected with operational amplifiers in feedforward and feedback paths so as to

form frequency selective boost and cut signal components.

U. S. Patent 4,316,060 (Adams, et al.) "Equalizing System" describes a system

5   for modifying an input signal representative of original sound so as to correct for

nonflat frequency response distortion caused by the audio equipment and

listening environment.

U. S. Patent 5,892,833 (Maag, et al.) "Gain and Equalization System and

10   Method" describes a multi-band digital gain and equalizer system for receiving

and processing audio signals.

U. S. Patent 5,194,832 (Iga) "Transversal Equalizer" describes an equalizer

having a specified number of rear taps.

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U. S. Patent 4,845,758 (Op de Beek, et al.) "Equalizer with Adjustable Band

Filters and a Digital Filter Suitable for Use in the Equalizer" describes a manually

operated or automatic equalizer with adjustable band filters.

20   U. S. Patent 5,841,810 (Wong, et al.) "Multiple Stage Adaptive Equalizer"

describes an adaptive equalizer which includes multiple, serially coupled

adaptive filter stages.

Brief Summary of the Invention

5   It is the objective of this invention to provide a multichannel digital filter bank circuit and a method implemented by cascading sub-filters of the recursive type suitable for graphically equalizing electrical signals received via a communication path. It is also an objective of this invention to produce equalized signals having minimal distortion of signal spectral characteristics including magnitude and

10   phase. The circuit of this invention is implemented with cascaded connections of first order or second order digital filters. It is an additional objective of this invention to provide for the programming of the individual transfer functions of the above digital filters so as to produce unity gain. This unity gain case results in an output signal which is an exact replica of the input signal with no delay. This

15   result indicates the minimal distortion introduced by the method of this invention.

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Brief Description of the Drawings

FIG. 1 shows a prior art conventional filter bank implemented with parallel

5   structure.

FIG. 2 shows the frequency response of the prior art parallel filter bank of

fig. 1.

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FIG. 3 shows a typical frequency response plot of the prior art parallel filter

bank of fig. 1 when all the channel gain settings are set to unity.

FIG. 4 shows the cascade implementation of this invention.

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FIG. 5 shows a typical frequency response plot of the cascade

implementation of this invention.

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Detailed Description Of The Invention

Fig. 4 shows a block diagram of the embodiment of this invention. The audio or electrical signal 450 to be equalized enters the first digital filter 410 of the

5 cascaded filter bank made up of digital filters H1, H2, H3, ..., Hm (410, 420, 430, 440). H1, H2, H3, ..., Hm represent the transfer functions of the digital filters in the serial filter bank just described. The resultant equalized signal 460 comes out of the filter represented by Hm 440.

The overall z-transform transfer function, H(z), of the composite filter bank for

10 implementing a graphics equalizer is given by

$$H(z) = H1(z)H2(z)H3(z) \ldots Hm(z)$$

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$H_i(z)$ controls the gain of the i th channel of the graphics equalizer where i=1,2,3,...,m. Hi(z) is not a bandpass filter but is either a notch or line enhancer depending on whether the spectral of that particular channel is to be attenuated

20 or enhanced. A typical frequency response plot for Hi(z) is shown in Fig.5. Hi(z) may be of any order. The plot of Fig. 5 represents the use of second order filters. However, if Hi(z) is 1st order, then it is given by

$$H_i(z) = \frac{1 - az^{-1}}{1 - bz^{-1}}$$

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$$|a| \text{ and } |b| < 1$$

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Furthermore, a and b must be of the same sign. If a is greater than b, then it is a notch. If a is smaller than b, then it is a line enhancer. If a is equal to b, then

5 Hi(z) = 1 and passes all signals without affecting the signals' spectral characteristics. Its gain at d.c. (or half sampling frequency depending on the signs of a and b is

$$\frac{1 - |a|}{1 - |b|}$$

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Back to Fig. 5, if Hi(z) is 2nd order, then it is given by

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$$H_i(z) = \frac{1 - 2g_i \cos(p_i)z^{-1} + g_i^2 z^2}{1 - 2r_i \cos(p_i)z^{-1} + r_i^2 z^2}$$

Both g, and r are positive and less than unity.

20 The gain 540 of Hi(z) at

$$\frac{p_i f_s}{2\pi}$$

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is determined by the values of g, and r, (where Fs, is the sampling frequency) and is given by

$$\frac{1 - g_i}{1 - r_i}$$

30 If g is greater than r, then it is a notch 530. If g is smaller than r, then it is a line enhancer 510. If g is equal to r, then Hi(z) =1 and passes all signals without affecting the signals' spectral characteristics 520.

If H1(Z) = H2(Z) = H3(Z) =   ... = Hm(z) = 1, then the overall H(z) = 1 and

the output is an exact replica of the input.

While this invention has been particularly shown and described with

Reference to the preferred embodiments thereof, it will be understood by those

5   Skilled in the art that various changes in form and details may be made without

Departing from the spirit and scope of this invention.

What is claimed is:

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